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ABSTRACT

The effectiveness of computer simulation versus laboratory procedures in teaching logic circuits was compared. Also investigated was the sequencing of these activities with a reading assignment. Subjects were 96 undergraduates who were tested using different pretests and posttests. An analysis of variance on the data gathered showed that sequence of instruction was a very important factor. Students who performed the activity (laboratory or computer simulation) first, followed by the reading assignment, scored significantly higher on the posttest compared to those who studied identical material in the opposite sequence. The laboratory procedure and computer simulation proved equally effective in teaching logic circuits. When posttest items were classified into "knowledge" and "transfer" categories, only the transfer items contributed to the difference between the two groups. The study concluded that setting up exploratory types of experiential activity prior to formal instruction results in better conceptual learning and better transfer compared to the reverse sequence. (Six data tables and 14 references are included.) (KC)

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EFFECTIVENESS OF COMPUTER SIMULATION VERSUS LAB, AND SEQUENCING OF INSTRUCTION, IN TEACHING LOGIC CIRCUITS

Abstract

The present study investigated the effectiveness of computer simulation versus laboratory procedure, and sequencing these activities with a reading assignment, in teaching logic circuits. Subjects were 96 undergraduate students. An analysis of variance on the data showed that sequence of instruction was a very important factor: Students who did the activity (laboratory or computer simulation) first, followed by the reading assignment, scored significantly higher on the posttest as compared to those who received identical material in the opposite sequence. It was found that both laboratory procedure and computer simulation were equally effective, in teaching logic circuits. When posttest items were classified into "knowledge" and "transfer" categories, it was found that only the "transfer" items contributed to the difference between the two sequential groups. The study concluded that exploratory type of experiential activity prior to formal instruction results in better conceptual learning and better transfer as compared to the reverse sequence.

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Introduction

In light of the widespread and increasing use of educational software, it is necessary to evaluate its effectiveness in comparison with traditional teaching methods. Educational software is categorized into four major types of presentations: drill and practice, tutorial, simulation, and problem-solving (Streibel, 1985). This study focused on "simulation" type of software. Lepper (1985) describes how drill and practice or tutorial formats are grounded in behavioral learning theory, and how simulation or problem-solving type of software reflects the cognitive perspective on learning. In assessing the educational importance of simulations in computer-assisted instruction, Crookall (1988) states "One might say simulation has come to the rescue of computer use in the classroom" (p. 3).

When computer simulations are compared to other media such as print, film, video, or lectures, a primary advantage claimed for them is increased transfer of learning (Alessi & Trollip, 1985; Reigeluth & Schwartz, 1989). Transfer of learning refers to students being able to apply what is learned during instruction to a new situation, usually the intended real performance. Although simulations are assumed to enhance transfer better than books or other media, "hands-on" instruction with real equipment is often assumed to have still better transfer (Alessi, 1988). However, simulations

may still be preferred for other reasons, notably cost and safety (Bork, 1986). Although the use of instructional computer-based simulation is increasing, the amount of research comparing it with laboratory activities is comparatively small.

This study attempted to compare the effectiveness of computer simulation versus laboratory activities in teaching logic circuits. Laboratory procedure represents the traditional type of instruction that involves "hands-on" experience. Simulations offer the potential for interactive and individualized learning.

In addition to the method of instruction, this study focused on sequencing of instruction. Most educators indicate that one of the major tasks in instructional design is to decide how to sequence all of the content that has been identified. The objective was to compare achievement of subjects who did the experiential activities prior to formal instruction with subjects who received identical material in the opposite sequence.

Purpose of the Study

This study was designed to examine the effects of two variables, in teaching logic circuits:

1. computer simulation versus laboratory experience, and
2. sequencing of instruction.

Theoretical Framework

The origins of the laboratory activity approach can be traced back to Dewey's (1938) problem-solving theory. This theory points out the importance of firsthand experience to learning. Its basic premise is that learning happens as a result of "doing" and "experiencing" things in the world. Dewey (1938) has written that laboratory experience where physical activity is suffused with the mental, is an effective learning medium.

The computer-based simulation activity in this study was based on the cognitive learning theory. This theory draws attention away from the importance of physical activity and focuses on the mental activity that takes place within the learner. According to Tennyson, Thurlow and Breuer (1987), problem-oriented simulations help develop higher-order thinking strategies and improve student cognitive abilities employed in the service of recall, problem solving, and creativity.

The other independent variable in this study was sequencing of instruction. Ausubel (1968) stated that the sequence in which learning occurs influences the stability of cognitive structures and thereby influences long-term retention and transfer. New knowledge is made meaningful by relating it to prior knowledge and optimization of prior knowledge is done through sequencing. Thus, sequencing is a

very important part of the instructional design.

Thomas and Hooper (1989), discuss the instructional use and sequencing of computer simulation, and its effect on the students' cognitive process. The authors state that computer simulations play two major roles: preparing students to learn new materials and testing materials that have been previously learned. When used prior to formal instruction, the program builds intuition and alerts the student to the overall nature of the process and the need for a deeper understanding. When used after formal instruction, the program offers the student an opportunity to apply the learned material.

Research Questions

The research questions examined in this study were:

1. Will there be a significant difference in achievement on a test of logic circuits between students using the computer simulation program and students doing the laboratory procedure?

2. Will there be a significant difference in achievement on a test of logic circuits between students who receive a reading assignment following the laboratory or simulation experience and students who receive identical material in the reverse sequence?

3. Will there be a significant interaction between method of instruction and sequencing of instruction in teaching logic circuits?

Delimitations of the Study

The limitations of this study were as follows:

1. The sample was limited to students at Iowa State University.
2. Neither the laboratory activity nor the simulation activity had recording mechanism to determine the level of student accomplishment in these activities.

Methodology

The two independent variables in this study were: (1) method of instruction, a nominal variable with two categories (computer-based simulation and laboratory activity); and (2) sequencing of instruction, a nominal variable with two categories (reading following lab or simulation experience and reading prior to lab or simulation experience). The dependent variable was the posttest score.

Subjects

The population for this study consisted of undergraduate students enrolled at Iowa State University, Ames, Iowa. The sample was made up of students enrolled in the Summer semester of 1989. A total of 96 subjects participated in the study.

Treatment

The computer simulation program was called HIGH WIRE LOGIC and was developed by Sunburst Corporation. In this program, students work with two sets of shapes; one set on a

high wire and another set that falls into the net. There are four basic shapes: triangle, hexagon, rectangle, and diamond. These shapes are either large or small. In addition, they may either be empty or filled. They have one of the four colors: green, blue, orange, or purple. The object of the game is for the student to write as many logic rules as possible that fit the shapes on the high wire, but do not fit the shapes in the net. The rules must be based on the logic types: AND, OR, AND-OR, AND-AND, OR-OR, and XOR (Exclusive-OR). Students score points for each correct rule written.

This computer-based software involved cognition of figural objects and their symbolic and semantic attributes. The program combined simulation and problem-solving techniques and involved interactive computing and graphics. The student was provided with a facility to manipulate and test ideas and hypotheses whilst aided by the computer. The students did this activity for 50 minutes.

Laboratory activity was the alternate experimental treatment. It was designed to be very similar to a lab that students would do as part of a 'logic circuits' course. As part of this activity, students were instructed to work at each of the four experiment stations. Each experiment station consisted of a logic circuit board called LOGI-TRAN TWO made by Fabri-Tek Education Systems, Inc. The inputs and

output for each of the four logic gates: AND, OR, NOT, and Exclusive-OR, were already wired. The switches could be turned on or off to result in different input combinations. The output of the logic gate was connected to a light bulb which was also provided on the logic board.

The students manipulated the input configurations of already built AND, OR, NOT and Exclusive-OR logic gates. However, the participants were not informed about the type of logic gate they were working with. Step-wise instruction sheets were provided at each station. The objective of each activity was to explore the operation of that particular logic gate. The last step on the instruction sheet urged the students to think about what they had observed in the process. The participants took 50 minutes to complete this activity.

The reading assignment was common to all participants. This booklet consisted of nineteen pages. The booklet elaborated on the following concepts: Digital levels, AND, OR, NOT, Exclusive-OR, NAND, and NOR logic gates, and combination logic. The description for each logic gate included a conversational example, logic symbol, truth table, and boolean operator. In combination logic, the process of constructing a boolean equation from a logic diagram was described by using an example. The participants were required to read the booklet for 40 minutes.

Instruments

The instruments used in this study were developed by the author. The pretest and posttest were designed to measure student understanding of logic circuits and hence belonged to the cognitive domain. Bloom's Taxonomy (1956) was used as a guide to develop blueprints for the pretest and the posttest.

The posttest was a paper-and-pencil test and consisted of 25 items. The test was administered to 72 undergraduate students at Iowa State University when the pilot study was conducted during Spring 1989. The reliability analysis of the test was based on these data. The Cronbach Reliability Coefficient was found to be 0.94. The pretest was a paper-and-pencil test and consisted of 19 items. On analyzing the pilot study data, the Cronbach Reliability Coefficient of the pretest was found to be 0.83. The content validity of these tests was confirmed by four professors at Iowa State University, who are knowledgeable in this area.

Research Design

The study was conducted using a 2 X 2 factorial design. The level of significance which is the Type I error rate (alpha) was set at 0.05. Before the experiment began, the Type II error rate (beta) was set at 0.05. In other words, the statistical power of the test was 0.95. The meaningful difference or effect size was one standard deviation. Since the significance criterion, power, and effect size were

already specified, sample size tables were used to determine the sample size N. The sample size was determined to be 25 in each of the four groups (Cohen, 1977). However, only 96 subjects participated in this study. As a result, beta increased to 0.06 and the power decreased to 0.94.

The subjects were randomly assigned to one of the four experimental treatments. A pretest was administered to all subjects prior to instruction. The pretest was helpful in assessing subjects' prior knowledge of logic circuits and also in testing initial equivalence among groups. A posttest was administered to measure treatment effects. A description of the four treatment groups is given below in Table 1.

TABLE 1. Treatment Groups

Group 1	R	Pretest	Lab	Reading	Posttest
Group 2	R	Pretest	Sim	Reading	Posttest
Group 3	R	Pretest	Reading	Lab	Posttest
Group 4	R	Pretest	Reading	Sim	Posttest

R: Random assignment
Pretest: Pretest administered
Lab: Laboratory procedure
Reading: Reading assignment
Sim: Computer-based simulation program
Posttest: Posttest administered

Findings

A total of 96 subjects participated in this study. All subjects were volunteer students from the College of Education. An 11-item questionnaire was developed to collect descriptive data on the participants. Results of the questionnaire revealed that the average age of the participants was 25 years with a range of 18 to 54 years. The mean grade point average was 2.99 on a four-point scale, with a range of 1.92 to 3.96. The participants were employed for an average of 18 hours per week and work hours ranged from zero to 48 hours.

The questionnaire also revealed that 63 participants were females and 33 were males. Six students were currently classified as freshman, 40 were sophomores, 34 were juniors, and 16 were seniors. Ninety-two participants reported that they had no formal education in logic circuits either in high school or in college. Four students stated that they had taken a course in digital electronics in high school but not in college. Only two participants indicated that they had studied logic circuits in both high school and college.

The total treatment lasted for 90 minutes. In order to avoid the problem of the students becoming "test-wise" the pretest and posttest were not parallel forms of the same test. Hence, the difference between the pretest and posttest scores was not meaningful. The posttest score was used as

the criterion variable. The mean, standard deviation, and range of the pretest and posttest scores for the four treatment groups are reported in Tables 2 and 3, respectively. In Table 3, 'NMax' refers to the number of students who achieved a maximum score of 25 on the posttest.

At first, one-way ANOVA was conducted on pretest scores for the four treatment groups. The one-way procedure yielded an F-ratio that was not statistically significant ($F = 1.52$, $p > 0.05$). Hence, it was concluded that pretest differences among treatment groups were not significant. The data were also tested for the assumption of homogeneity of variance using Bartlett's test. It was found that the variances were not significantly different ($F = .335$, $p > 0.05$). The data were then analyzed to determine the treatment effects using the analysis of variance (ANOVA) procedure which is most appropriate for this two factor design.

Research Question I

Will there be a significant difference in achievement on a test of logic circuits between students using the computer simulation program and students doing the laboratory procedure?

The overall mean of the posttest scores for the participants in the group that did the laboratory procedure (17.28) was slightly higher than the group that did the computer simulation (16.64). However, an analysis of

variance on the data, did not show a significant difference between the two groups. The result is given in Table 4.

Research Question II

Will there be a significant difference in achievement on a test of logic circuits between students who receive a reading assignment following the laboratory or simulation experience and students who receive identical material in the reverse sequence?

The overall mean of the posttest scores for the participants in the group that did the activity before the reading assignment (18.07) was much higher than the group that did the activity after the reading assignment (15.84). This difference was significant at the 0.001 alpha level. This result is presented in Table 4.

In order to identify where the differences occurred, the posttest items were then analyzed and classified in two categories:

1. knowledge, and
2. transfer.

At the beginning of the study, Bloom's taxonomy was used to develop a blueprint for the posttest. The items that belonged to the "knowledge" and "comprehension" classifications of Bloom's taxonomy were categorized as "knowledge" items. These items pertained to logic symbols

and truth tables for different logic gates. The items that belonged to the "application", "synthesis", "analysis", and "evaluation" classifications of Bloom's taxonomy were categorized as "transfer" items. These items dealt with applications of logic gates in real life situations, and synthesis or analysis of the concepts. Of the 25 posttest items, 10 were classified as "knowledge" items and 15 were "transfer" items.

A t-test was used to determine the differences between the two sequential groups for both types of items. The result of this analysis is presented in Table 5. It can be seen that only the "transfer" items contributed to the difference between the two sequential groups.

Research Question III

Will there be a significant interaction between method of instruction and sequencing of instruction in teaching logic circuits?

An analysis of variance on the data did not substantiate the interaction effect due to method of instruction and sequence of instruction. The result is given in Table 4.

Exploratory Analysis

Though treatment effects were analyzed, no information was obtained regarding the relationship between the posttest score and other independent variables. The regression

analysis procedure was used for exploratory purposes. Results showed that the posttest score correlated highly with the pretest score, sequence of instruction, gender, number of hours the participants worked per week, and student grade point average. The Pearson correlation coefficients for the variables are given in Table 6.

The stepwise method was used to enter the independent variables. The variables that entered the regression equation were: pretest, sequence of instruction, and gender. The multiple correlation coefficient (R) was found to be 0.52. Approximately 27 percent of the variance in the posttest score was attributable to the variance of the combined predictor variables. Since gender entered the regression equation, it was necessary to determine the number of females and males in each of the four treatment groups. The distribution of females and males in the four treatment groups was not significantly different.

The posttest score was significantly related to other factors besides the treatment variables. Hence, an analysis of covariance procedure was used to gain statistical control. Pretest and student demographics that correlated significantly with the posttest score were entered as the covariates. It was found that sequence of instruction emerged as a very significant factor ($p < 0.001$). There was no significant difference between the two methods of

instruction. Also, the interaction effect was not significant.

Discussion of the Findings

As discussed in the earlier section, items that involved "transfer" contributed to the difference between the two sequential groups. There was no significant difference between the two methods of instruction.

Sequencing of Instruction

The participants were instructed that the objective of laboratory or simulation activity was to explore the operation of logic gates. When these activities occurred prior to the reading assignment they may have been helpful to:

1. provide motivation,
2. alert students to the overall nature of the process,
3. provide an organizing structure,
4. serve as a concrete example, or
5. expose areas of knowledge deficiency.

Students who did the laboratory procedure prior to reading, observed that only certain input combinations produce a nonzero output. They may have understood some general concepts:

* not all input combinations result in a nonzero output, and
* input combinations that result in a nonzero output are

different for various logic gates.

When these students read the booklet, they could relate the material to prior experience. This may have helped them to get a better understanding of the subject matter.

The computer simulation program exposed the student to general concepts in logic circuits. The students may have observed that:

* when the word 'AND' connects two or more conditions, the consequence will be true if and only if all the conditions are true,
* when the word 'OR' connects two or more conditions, the consequence will be true if either one or all conditions are true, and
* when the word 'XOR' connects two conditions, the consequence will be true only when either one of the conditions is true.

Students who did the simulation first, got some idea about the technical meaning of AND, OR, and XOR words. These students were probably able to relate these general concepts as applied to logic circuits. This sequence helped the students to better understand the material.

Students who read the booklet first, had no exposure to logic gates. They may have tended to memorize the material while reading because they probably could not relate it to any prior experience. When these students later did the

activity, it gave them an opportunity to apply what they had learned in the booklet, but did not really serve as an integrator. Thus, there may have been significantly less meaningful learning as compared to the students who read the booklet after doing the activity.

This discussion supports the learning theories proposed by proponents of 'discovery learning'. According to Gagne (1987), exploratory strategies prior to formal instruction instill greater degrees of autonomy and intuition in the learner. This increases students' ability to integrate information and results in better retention and transfer. Since a high percentage of the participants in this study had no background in logic circuits, they benefited significantly from the laboratory or simulation activities that set the stage for subsequent learning. It must be noted that the results might have been different if the participants had some prior knowledge of the concepts involved in logic circuits.

Method of Instruction

It will be appropriate here to analyze the characteristics of the two activities. Laboratory activity is considered more concrete as compared to computer simulation which is more abstract in nature. However, the laboratory activity also had an abstract component: Students were not given any information regarding the outcome of each

procedure but were instructed to observe and analyze the outcomes. Thus, both laboratory and simulation activities were designed at a higher level of abstraction.

The objective of both activities as described in the instructions to the students, was to explore the operation of logic gates. In other words, both activities were exploratory in nature. Thus, although there was variation in the nature of these activities, their overall 'cognitive' effect may have been very similar.

Implications for Instruction

The traditional sequence of instruction for teaching logic circuits has been: formal presentation of material followed by experiential activities. However, based on the findings of the present study, it can be concluded that advance exposure to experiential activities aided in the learning of unfamiliar, technical material, and resulted in significantly better posttest performance.

In situations where the objective of instruction is for students to learn the facts without their application or transfer, sequence of instruction is not a significant factor. However, if the educational goal is for students to be able to apply and transfer the knowledge, then experiential activities should occur prior to formal presentation of the material. Also, these activities should

be exploratory in nature, designed to stimulate the students' thinking process.

Future research studies need to investigate the mental models or schemata which students employ for understanding the concepts involved in logic circuits. It is also recommended that studies be designed to investigate the effectiveness of computer simulations for improving higher-order thinking skills.

TABLE 2. Summary of Pretest Scores by Treatment Groups

Treatment	N	Mean	SD	Min	Max
Lab-Reading	24	9.04	2.69	4.0	15.0
Sim-Reading	24	9.83	2.81	4.0	17.0
Reading-Lab	24	9.75	2.64	5.0	14.0
Reading-Sim	24	8.46	2.08	4.0	13.0

TABLE 3. Summary of Posttest Scores by Treatment Groups

Treatment	N	Mean	SD	Min	Max	NMax
Lab-Reading	24	18.04	2.69	12.0	25.0	1
Sim-Reading	24	18.10	2.83	13.0	25.0	1
Reading-Lab	24	16.32	3.44	10.0	22.0	0
Reading-Sim	24	15.71	3.16	10.0	25.0	1

TABLE 4. Analysis of Variance on Posttest Scores

Source of Variation	df	Mean Square	F-value	p
Method	1	10.01	1.04	.311
Sequence	1	119.26	12.35	.001***
Method x Sequence	1	12.04	1.25	.267
Residual	92	9.66		

***p < .001.

TABLE 5. Result of t-test on the two Sequential Groups

Items	Group	N	Mean	SD	t	p
Knowledge	1	48	9.19	1.76	1.71	.09
	2	48	8.73	1.69		
Transfer	1	48	8.88	2.47	3.53	.001***
	2	48	7.03	2.66		

Group 1: Activity before Reading

Group 2: Activity after Reading

***p < 0.001.

TABLE 6. Pearson Correlation Coefficients

	Pre	Post	Age	Sex	Year	GPA	Work	Seq
Pre	1.00	.41***	.02	.14	.10	.18*	-.18*	-.06
Post		1.00	-.04	.25**	.11	.19*	-.25**	.35***
Age			1.00	-.13	.31***	.47***	.04	-.13
Sex				1.00	-.10	-.09	-.14	.15
Year					1.00	.19*	.04	.03
GPA						1.00	.06	-.12
Work							1.00	.01
Seq								1.00

*p < 0.05, **p < 0.01, ***p < 0.001.

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